

The invention in which an exclusive right is claimed is defined by the following:

1. A method for detecting internal bleeding, comprising the steps of:
  - (a) processing ultrasound data for an internal site; and
  - (b) identifying tissue vibrations for the internal site in real time; and
  - (c) detecting the internal bleeding as a function of the tissue vibrations.
2. A method for detecting internal bleeding using ultrasound data, comprising the steps of:
  - (a) processing the ultrasound data in real time to identify tissue vibrations at a site, producing a tissue vibration signal; and
  - (b) filtering the tissue vibration signal, yielding a signal from which any contribution to the tissue vibration from a source other than bleeding at the site has been substantially minimized, said signal providing an indication of the internal bleeding.
3. The method of Claim 2, further comprising the step of determining a location of the internal bleeding in real time using the signal.
4. The method of Claim 2, further comprising the step of employing the signal for producing a vibration image indicating one or more locations of the internal bleeding.
5. The method of Claim 2, wherein the step of processing the ultrasound data comprises the steps of:
  - (a) estimating a correlation signal from an ensemble of the ultrasound data;
  - (b) carrying out an eigendecomposition of the correlation signal to identify a signal subspace and a noise subspace;
  - (c) estimating a frequency of dominant vibration components in the signal subspace and the noise subspace; and
  - (d) based upon an estimate of the frequency of the dominant vibration components, determining a vibration amplitude and a vibration frequency, at



least one of the vibration amplitude and the vibration frequency comprising the tissue vibration signal.

6. The method of Claim 2, wherein the step of processing the ultrasound data comprises the steps of:

- (a) computing reflection coefficients of an autoregressive process from an ensemble of the ultrasound data;
- (b) computing linear prediction filter coefficients from the reflection coefficients;
- (c) estimating a power spectrum from the linear prediction filter coefficients and detecting peaks in the power spectrum; and
- (d) based upon an estimate of the power spectrum and the peaks, determining a vibration amplitude and a vibration frequency, at least one of the vibration amplitude and the vibration frequency comprising the tissue vibration signal.

7. The method of Claim 2, wherein the step of processing the ultrasound data comprises the steps of:

- (a) estimating a mean clutter velocity from an ensemble of the ultrasound data, using autocorrelation;
- (b) down mixing the ultrasound data with the mean clutter velocity, producing a down mixed signal;
- (c) computing a phase of the down mixed signal and a mean phase of the down mixed signal;
- (d) subtracting the mean phase from the phase of the down mixed signal, producing a residual phase;
- (e) decomposing the residual phase into its dominant components; and
- (f) applying energy and frequency thresholds to substantially suppress any contribution to the tissue vibration due to noise and blood flow, yielding an estimate of vibration amplitude and vibration frequency of tissue.

8. The method of Claim 7, wherein the step of decomposing the residual phase comprises the steps of:



- (a) estimating a correlation matrix from the residual phase; and
- (b) performing an eigendecomposition of the correlation matrix to determine the dominant components.

9. The method of Claim 7, wherein the step of decomposing the residual phase comprises the steps of:

- (a) estimating a correlation matrix from the residual phase; and
- (b) performing a partial eigendecomposition of the correlation matrix using iterative QR factorization to determine the dominant components.

10. The method of Claim 2, wherein the tissue vibrations are identified by processing the ultrasound data from multiple depth locations.

11. The method of Claim 2, wherein the step of filtering comprises the step of filtering out clutter and noise at frequencies that are substantially lower than an expected frequency range of tissue vibrations corresponding to bleeding at the site.

12. The method of Claim 2, wherein the step of filtering comprises the step of filtering out noise that is at frequencies that are substantially higher than an expected frequency range of tissue vibrations corresponding to bleeding at the site.

13. The method of Claim 2, further comprising the step of confirming that the tissue vibrations correspond to internal bleeding at the site by placing a Doppler sample volume at a location of the tissue vibration, producing a tissue vibration spectrum.

14. The method of Claim 2, further comprising the step of displaying a vibration image using the signal, wherein the step of displaying the vibration image comprises the step of displaying at least one of a vibration amplitude image and a vibration frequency image of the site.

15. The method of Claim 2, further comprising the step of displaying a vibration image using the signal, in connection with a color-flow image of the site, substantially in real-time.



16. The method of Claim 2, wherein the signal is employed to provide at least one of a palpable and an audible indication of the internal bleeding at the site.

17. The method of Claim 2, further comprising the step of determining a bleeding rate using a frequency and an amplitude of the tissue vibrations.

18. A memory medium having machine instructions for carrying out the steps of Claim 2.

19. Apparatus for detecting bleeding at an internal site using ultrasound, comprising:

- (a) an ultrasound transducer;
- (b) a control system coupled to the ultrasound transducer to control its operation; and
- (c) a tissue vibration processor that processes the ultrasound to identify tissue vibrations caused by internal bleeding, producing a signal indicating the internal bleeding.

20. The apparatus of Claim 19, wherein the signal produced by the tissue processor localizes the internal bleeding by determining a location of the tissue vibrations.

21. The apparatus of Claim 19, wherein the signal produced by the tissue vibration processor is usable to produce a vibration image in which the tissue vibrations indicate a location of the internal bleeding.

22. The apparatus of Claim 21, further comprising a display on which the vibration image is presented, the vibration image indicating a location of the internal bleeding.

23. The apparatus of Claim 19, wherein the signal produced by the tissue vibration processor is audible and includes characteristics that indicate the internal bleeding.



24. The apparatus of Claim 19, wherein the signal produced by the tissue vibration processor is employed to provide a palpable indication of the internal bleeding.

25. The apparatus of Claim 19, wherein the tissue vibration processor comprises an application specific integrated circuit.

26. The apparatus of Claim 19, wherein the tissue vibration processor comprises a general purpose processor that executes software to identify the tissue vibrations and produce the signal.

27. The apparatus of Claim 19, wherein the tissue vibration processor determines a bleeding rate from a frequency and an amplitude of the tissue vibrations.

28. The apparatus of Claim 19, wherein the tissue vibration processor identifies the tissue vibrations, producing a tissue vibration signal, and filters the tissue vibration signal, producing a filtered signal from which any contribution to the tissue vibration from a source other than bleeding at the internal site has been substantially minimized.

29. The apparatus of Claim 28, wherein the tissue vibration processor determines tissue vibrations at the internal site by:

- (a) estimating a correlation matrix from the color-flow signal;
- (b) carrying out an eigendecomposition of the correlation matrix to identify a signal subspace and a noise subspace;
- (c) estimating a frequency of dominant vibration components in the signal subspace and the noise subspace; and
- (d) based upon an estimate of the frequency of the dominant vibration components, determining a vibration amplitude estimate and a vibration frequency estimate, at least one of the vibration amplitude estimate and the vibration frequency estimate comprising the tissue vibration signal.

30. The apparatus of Claim 28, wherein the tissue vibration processor determines tissue vibrations at the internal site by:

- (a) computing reflection coefficients from the color-flow signal;



- (b) computing linear prediction filter coefficients from the reflection coefficients;
- (c) estimating a power spectrum and detecting peaks in the power spectrum; and
- (d) based upon an estimate of the power spectrum and the peak, determining a vibration amplitude estimate and a vibration frequency estimate, at least one of the vibration amplitude estimate and the vibration frequency estimate comprising the tissue vibration signal.

31. The apparatus of Claim 28, wherein the tissue vibration processor determines tissue vibrations at the internal site by:

- (a) estimating a mean clutter velocity from the color-flow signal, using autocorrelation;
- (b) down mixing the color-flow signal with the mean clutter velocity, producing a down mixed signal;
- (c) computing a phase of the down mixed signal and a mean phase of the down mixed signal;
- (d) subtracting the mean phase from the phase of the down mixed signal, producing a residual phase;
- (e) decomposing the residual phase into its dominant components; and
- (f) applying energy and frequency thresholds to substantially suppress any contribution to the tissue vibration due to noise and blood flow, yielding an estimate of vibration amplitude and vibration frequency of tissue.

32. The apparatus of Claim 31, wherein the tissue vibration processor decomposes the residual phase by:

- (a) estimating a correlation matrix from the residual phase; and
- (b) performing an eigendecomposition of the correlation matrix to determine the dominant components.

33. The apparatus of Claim 28, wherein the tissue vibration processor filters the tissue vibration signal by filtering out clutter and noise at frequencies that are



substantially lower than an expected frequency range of tissue vibrations corresponding to bleeding at the site.

34. The apparatus of Claim 28, wherein the tissue vibration processor filters the tissue vibration signal by filtering out clutter and noise at frequencies that are substantially higher than an expected frequency range of tissue vibrations corresponding to bleeding at the site.

35. The apparatus of Claim 19, wherein the tissue vibration processor further confirms that vibrations displayed in the vibration image correspond to bleeding at the site by placing a Doppler sample volume at a location of the tissue vibration, producing a tissue vibration spectrum.

36. The apparatus of Claim 19, wherein the display presents at least one of a vibration amplitude image and a vibration frequency image of the internal site.

37. The apparatus of Claim 19, further comprising a B-mode processor that produces a grayscale image showing underlying anatomy of the internal site, so that the display selectively presents at least one of a B-mode image of the internal site and the tissue vibration image of the internal site, substantially in real time.

38. The apparatus of Claim 19, further comprising a color-flow processor, so that the display selectively presents at least one of a color-flow image of the internal site and the tissue vibration image of the internal site.

39. The apparatus of Claim 19, further comprising a Doppler processor.